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Copper.

WORDS which have a strict technical significance are frequently used popularly in a loose sense, sometimes causing difficulties of considerable political and commercial importance. The treatment of the word "copper" in the proposals of the Ottawa Convention appears to be a case in point, since, so far as one can gather from the statements made in the Press, it is intended to impose a serious Empire Preference Duty on this metal. Now the term "copper" is loosely used to cover a range of materials which from the technical point of view differ widely in value and importance. They include electrolytic copper, fire-refined or "best select" copper, and Bessemer copper. Of these, the electrolytically refined or cathode copper is, of course, the highest grade material, having a high degree of purity and commanding a correspondingly higher price. The other two varieties of copper, however, are of very considerable importance for many branches of industry in this country, yet they rest upon a totally different footing, in many respects, as compared with the electrolytic material. The Ottawa proposals, however, appear to make no distinctions, and yet there is every reason to believe that the imposition of a duty on non-Empire copper of the fire-refined and Bessemer types would entail a serious hardship for certain branches of the copper industry in this country.

The case is important not only on its own account, but because it serves as an example of the difficulties which administrators have to face in legislating for modern technical industries, and it illustrates the necessity, upon which we have frequently dwelt here, that the best possible technical and scientific advice should be available where administrative or legislative action dealing with technical matters is contemplated. It is, in fact, necessary that those most thoroughly acquainted with these technical and scientific questions should be given an active part in the framing of proposals rather than that they should merely be consulted more or less after the event. From this point of view we may perhaps consider the case, in the present instance, in some detail.

Electrolytic copper is substantially free from other elements or impurities, and, in particular, from bismuth, antimony, and arsenic. For this reason, it furnishes the raw material for the highest grades and most expensive qualities of copper and copper alloy products, but it is too costly a raw material to be used for a variety of copper articles which constitute a very important element in British industry. The alternative grades of copper, such as "Bessemer" and "fire-refined" are far less pure. They contain a considerable number of impurities in varying quantities. Provided that the most injurious of these impurities are not present in excessive amounts, this type of copper can be and is used extensively for the production of such articles as plates, pipes, tubes, and also for the making of alloys. As it happens, however, the quantity and nature of the impurities present varies with the source from which the copper is derived. The process of fire refining is able to eliminate, more or less completely, some undesired impurities, particularly sulphur. Others, however, cannot be removed by this process, and the quantity remaining in the finished copper depends upon the quantity present in the original blister copper from which the material has been refined. This is particularly true of bismuth, which is probably the most injurious impurity commonly found in copper. For some purposes specifications require that this element shall not be present except in the most minute amounts. In some cases the limiting amount is set down as 0·0001 per cent., an amount so small that it can scarcely be determined with accuracy by current methods of chemical analysis. For a great many purposes, however, a much larger proportion of bismuth is admissible, and a limit of 0·005 per cent. is frequently adopted. When we come to higher contents of bismuth, however, difficulties are apt to arise from the injurious influence of that element. It is true that in the presence of a considerable amount of oxygen, as well as arsenic, the ill effects of bismuth, even when it is present to the extent of 0·02 per cent., can be neutralised, although very great care is required in adjusting the oxygen content or "pitch" of the copper to the proper point. This, however, is done successfully with at least one well-known brand of copper. On the other hand, at the present time, large quantities of copper have to be produced in the "de-oxidised" condition, being made either initially "oxygen free" or being freed from nearly the whole of their oxygen content by the use of a de-oxidiser, such as phosphorus, lithium, beryllium, &c. The influence of impurities on copper has in recent years been studied very exhaustively by metallurgical investigators, particularly at the National Physical Laboratory in the course of a research carried out for the British Non-Ferrous Metals Research Association. These researches have elucidated and explained the interaction of bismuth with oxygen and with oxygen together with arsenic or antimony. The manner in which the presence of what would otherwise be an injurious percentage of bismuth can be neutralised by this combination with oxygen and arsenic or with oxygen and antimony has been very clearly demonstrated. It has also been

shown, however, that in the absence of oxygen the ill effects of bismuth can only be overcome to a limited extent, even by the addition of very appreciable quantities of arsenic or antimony. The authors of these researches have, moreover, repeatedly called attention to the fact that their results are applicable only to material produced under conditions similar to those prevailing in their experiments, which were necessarily made with small quantities of metal which were allowed to cool rapidly from the molten state. It cannot be assumed that equally good results in regard to the mutual neutralisation of impurities can be anticipated or guaranteed where large masses of copper which necessarily cool slowly are concerned. Further, fire-refined copper commercially produced always contains impurities other than those which have just been discussed, and it is known that some of these, and more especially nickel, exert an adverse influence on the neutralising effect of arsenic or antimony in regard to bismuth. On the basis of the best modern knowledge, therefore, it would be highly unwise for any copper manufacturer in this country to be content to accept a copper supply containing more than 0·005 per cent. of bismuth, especially if, as is the case at the present time in most branches of the industry, the copper is to be used in the deoxidised condition.

It is this point which raises the serious difficulty in connection with the Empire Preference proposed at Ottawa. It appears to be the fact that the supply of Empire-produced copper other than electrolytic for which a bismuth content not exceeding 0·005 per cent. can be guaranteed is altogether inadequate to meet the requirements of British copper manufacturers. The use of electrolytically refined copper for the purposes for which Bessemer and fire-refined copper are at present used is out of the question on the grounds of cost, and therefore the British manufacturers must for some time to come rely upon non-Empire copper for their supplies.

A consideration of these points will show that the proper adjustment of a preferential duty on copper is by no means the simple matter which it might at first sight appear to be, and that, if serious hardship is not to be inflicted on certain branches of industry in this country, the imposition of such duties must be guided by highly technical considerations. Of these we have pointed out only a few, since the ultimate question whether Empire producers of Bessemer and fire-refined copper can at any future time provide material of the requisite purity raises another series of problems connected with the nature of the ores available and the refining process which can be successfully used, whether on technical or economic grounds. We trust that the impressions conveyed by the published accounts of the Ottawa proposals, in which the word "copper" is referred to without qualification, are misleading, and that, for the present at all events, the new duties are intended to apply to electrolytic copper only. Failing this, we should be face to face with a serious error in political and administrative action arising from the inadequacy of technical and scientific advice, and in that case it would be necessary to seek means to rectify the error by administrative or parliamentary action before excessive hardship is inflicted on industry. Even if only a verbal error has been made by the use of the word "copper" without qualification, much irritation and anxiety has been caused, which, we suggest, could and should have been avoided if adequate consideration had been given to the technical and scientific aspects of such proposals.

Results of Research.

THAT the application of research to industry in general and to the metallurgical industries in particular has borne most valuable fruit can be proved by many examples, and is, indeed, formally admitted by most of those concerned with industry. Such admission is, however, very often made on general principles with the reservation—sometimes expressed, but more often merely mental—that its value for the particular branch of industry with which the individual is concerned may be doubted, at all events when the cost is considered. It is therefore highly satisfactory to find, as has happened quite recently, the head of a great industrial concern—in this case textile, and not metallurgical—announcing that as the result of prolonged researches his firm has solved one of the outstanding problems of the industry. This is a case where sufficiently firm faith in the value of the scientific method, backed by the courage to undertake the necessary expenditure and to allow the necessary time, has been fully rewarded, and it is particularly gratifying to find that this has been done by British investigators working for a British firm.

There is, however, one feature about this particular case which is remarkable. We are told that a research organisation was set up specifically with the object of finding the solution to one particular problem—in this case the research was undertaken to discover means whereby non-creasing qualities such as are found in woollen fabrics can be conferred upon cotton and artificial silk. We have here a case in which an industry knew exactly what was wanted and set about, with great success, to find it. This is a combination of circumstances which is by no means common, however, and it remains to be seen whether, in the ultimate issue the solution of this specific problem will really prove to be the most important result achieved by the researches which have been carried out. There are, of course, many instances in which an industry is in a position to state a definite objective for research, the attainment of which is known to be of great commercial value. It has often happened, however, that the problems thus set for research have not proved as fruitful as had been expected, partly because they proved excessively difficult in relation to existing knowledge and available methods of investigation, and partly because other advances, made either at the same time or shortly afterwards, rendered the solution of that particular problem much less important than had been anticipated. Where a problem can be found which is regarded as of first-rate importance and which, at the same time, is not excessively difficult to solve, striking success is the reward, but this is to some extent a matter of good fortune, since it is extremely difficult to predict for any given problem that either of the above conditions apply. It is this fact which no doubt has led to disappointment in some cases when industry has sought to find quick solutions for pressing problems by means of research, and it is clear that the only wise course in the selection of such problems for attack must lie in the close collaboration of the man highly skilled in the industry with one equally highly skilled in research, in order that both factors may receive adequate consideration. It must, however, be borne in mind that an attack on a new industrial problem very often requires the development of new methods of research and of new fundamental knowledge. If therefore researches

directed towards the solution of specific problems are to have a good chance of success, they must go forward parallel with others of a more general and fundamental character. It may not be either possible or desirable for these to be carried out in the laboratories of individual firms, but our research associations, our Government research laboratories and our universities and colleges provide facilities for their pursuit. Thus we think it highly probable that the research to which we have referred above owes some of its success to parallel advances on more general lines made by the Cotton Research Association and elsewhere. The point we desire to make is that even where a firm has established research laboratories of its own for research purposes, it is still to its own interest to support the work on similar subjects by research associations and other institutions.

There is, however, another aspect of the question to which we would draw attention, and that is that some of the most striking advances derived from research results have come in directions never foreseen when the work was begun. An organised attack on a clearly defined problem naturally appeals to the business man and to the organising mind generally, but it is very unwise to carry such a predilection too far. Many researches aimed at an almost unattainable goal have yielded results of first-rate importance which might easily have been neglected as "side issues" or even condemned as "side tracks." As Sir Oliver Lodge expressed it not long ago, the difference between the man who makes discoveries and the one who does not is that the former regards unexpected facts and observations as interesting clues to new knowledge, while the latter looks upon them as unimportant or even as a nuisance. It is, of course, quite possible to follow these unexpected things too far, and thus to stultify or at least to delay the progress of the work. What is needed is an open and observant mind and a fair balance between the organised pursuit of a specified objective and the readiness to take advantage of every promising opening that offers itself. Even in so favourable a case as that which we have discussed above, however, where the principal objective has been attained, it is quite possible that it will ultimately be found that certain "side tracks" if or when pursued lead to even bigger things. This much is certain, however, that the strikingly successful result must do much to encourage both those who have worked at its achievement and those who look on from other fields of activity. May it give fresh courage to those who still hope that the application of scientific research may help British industry to become the most progressive and efficient in the world.

Electrical Measurement of Corrosion.

One of the difficulties in quantitative work on corrosion is that the attack is usually not uniform, but commences at a number of isolated points, and the progress of the corrosion over the surface is determined by the apparently chaotic behaviour at these separate seats of action. This lack of uniformity in the attack has doubtless been largely responsible for the impression that any attempt to obtain reproducible results for the measurement of corrosion must fail. The notorious lack of reproducibility which until quite recently has characterised all corrosion measurements has done much to strengthen this impression.

The establishment of the electrochemical nature of corrosion has of late given considerable encouragement to the development of a method which seems to offer possibilities as an acceleration test, whilst at the same time tending to eliminate the irregularities referred to above. It depends on the principle that corrosion is produced by electric currents flowing from anodic to cathodic areas on the metal surface; if the process can be imitated in an electrolytic cell then the principles controlling the corrosion velocity may be discovered by means of the laws governing the current in this cell.

An attempt to use such a method for studying the corrosion rate of cast iron in concentrated sulphuric acid is described in a paper by M. T. Michailoff—*Korrosion und Metallschutz*, 4, 1932, page 85. The research arose out of difficulties encountered when using cast iron containers for sulphuric acid; it is, however, opportune to discuss certain points of fundamental importance in relation to more general issues, particularly in view of the tendency at the present time to seek "short-cut methods" in corrosion research. The desirability of the electrical method is discussed in the paper, and undoubtedly it would be most valuable if within a few minutes an order could be assigned to the expected corrosion rates for a number of metals. If the external conditions are fixed the properties of the different alloys will be characterised by the velocity and distribution of corrosion, which in turn will be determined by the physico-chemical properties of the metal relative to the conditions.

The experimental procedure follows that of F. Tödt's "Corrosimeter." In this instrument the corroding metal is joined to a more noble one, such as platinum, to form the corroding liquid with a galvanic cell which is short-circuited through a sensitive current meter. Tödt claims that, with neutral salt solutions, if the rate of diffusion of oxygen to the platinum surface is the same as that to an equal surface of the corroding metal, and if the course of the anodic reactions is unchanged by increasing the current density, the current flowing between the two metals is a measure of the corrosion of the less noble having an area equal to that of platinum. Any circumstances which alter the rate of corrosion, such as film formation, are considered to be reflected in a change in the current density at the electrodes, and conversely a change in the current density indicates changes in the mechanism of corrosion.

The particular problem under discussion was to investigate the relative behaviour under the same working conditions of three types of cast iron, B., C. and D, of known composition and microstructure. The corrosion of cast iron in concentrated sulphuric acid is slow, but increases considerably with dilution; the experiments were made with 87 per cent., 92 per cent., and 98 per cent. acid at temperatures 20, 60, 90, and 300 deg. Cent.

On dipping the cast iron into the acid there is a marked evolution of gas bubbles, which soon ceases. Simultaneous potential measurements (E) against a platinum electrode show an E.M.F. of about 1 volt, which falls after about thirty minutes to a steady value of about 0·5 volt. This value is characteristic of the particular metal and the experimental conditions, and can usually be reproduced to within 10 m.v., the degree of reproducibility depending on the metal. Simultaneous current measurements (i/S) also showed a constant final value. The experiments lasted for twelve hours, after which the loss of weight was estimated and a figure calculated giving the

average loss of thickness in millimetres per month (π). The results are shown in the accompanying table.

Cast Iron—Type B.

°C.	H_2SO_4.	E.	i/S.	π
Deg.	Per cent.			
20	98	0·46	0·10	0·07
	92	0·50	0·12	0·07
	87	0·42	0·07	0·06
60	98	0·50	0·18	—
	92	0·48	0·15	0·17
	87	0·44	0·20	0·24
90	98	0·43	0·50	0·41
	92	0·41	0·30	0·42
	87	0·40	0·33	0·93
300	98	0·30	2·0	17

Cast Iron—Type C.

20	98	0·36	0·06	0·12
	92	0·52	0·13	0·09
	87	0·52	0·22	0·10
60	98	0·35	0·20	—
	92	0·53	0·61	0·30
	87	0·58	0·81	0·40
90	98	0·35	0·50	0·52
	92	0·51	0·93	0·54
	87	0·57	3·9	0·60
300	98	0·22	2·0	6·8

Cast Iron—Type D.

20	98	0·57	0·20	0·05
	92	0·41	0·06	0·04
	87	0·45	0·30	0·08
60	98	0·53	0·40	—
	92	0·50	0·25	0·16
	87	0·54	0·60	0·35
90	98	0·52	0·80	0·56
	92	0·48	0·40	0·65
	87	0·48	0·60	0·90
300	98	0·25	2·0	9·17

These results show definitely that there is no kind of proportion between either the potential or the current density and the corrosion. The author comes to the conclusion that, if observations of potential, current density, and corrosion are made for one set of conditions, it is not possible to predict the corrosion in another set of conditions by observations of potential and current density, *i.e.*, the corrodibility of cast iron in concentrated sulphuric acid cannot be determined by potential and current measurements, or, in other words, the Tödt method is not a universal method for measuring or predicting corrosion rates.

Before discussing the significance of these results it is interesting to compare statements by other workers in this field. Tödt—*Z. Elektrochem.*, 1928, 34, page 853, and subsequent papers—himself gives results with aqueous solutions which establish agreement between the current density and the loss of the anodic metal, and he asserts that the passivity phenomena due to film formation can be followed more closely by such current measurements than by weighing. K. Konopicky (*Zeits. f. Elektrochem.*, 36, 1930, page 244) claims that potential measurements provide a rapid method of testing the corrodibility of iron rusting in salt solutions and of acid-resisting steels. The method is considered sufficiently accurate to select metals which will give the best results under given conditions.

Contrary to these results, Blum and Rawdon, Am. Elec. Chem. Soc., 52, 1927, page 403, using a method of Anderson and Enos, by which a definite current is made to pass through the cell, found no correspondence between the loss in weight and the corrosion produced when the same metals are subjected to simple immersion in the same solutions. It is obvious that such a method has not the merits of those similar to Tödt's. The current, instead of being left to its own devices, is controlled externally; even so, it may be asked whether it has any less real relation to actual corrosion phenomena than other methods of the "Tödt" type, where a current is encouraged to flow from one metal to another relatively cathodic one. In the first place, such methods can only be considered at all when the loss of the anodic metal corresponds to the coulombs which have passed through the cell. If the current is approximately constant then a measure of the current may be used in place of coulombs. The conditions deciding the degree of correspondence will vary from one case to another. If the corrosion is in a neutral solution and the rate is under oxygen control, then it will only be possible to obtain correspondence if no oxygen reaches the anode. If oxygen does reach the anode, then attack will occur there independently of the current effects. In practice it will be impossible to ensure that no oxygen reaches the anode, but any such effect may be small compared with that due to the current. The presence of protective films will be reflected by potential measurements and the occurrence of relatively small currents. But it is difficult to see how in such cases there will be any correlation between current and loss of metal. If the problem is one of acid corrosion the controlling factor may be the hydrogen ion concentration or the hydrogen over-voltage. For a correspondence between anodic attack and current all the hydrogen displaced by the dissolving metal must be liberated at the cathode, and this will only happen if the cathode has a lower hydrogen over-voltage than any constituent of the anode. With cast iron the low over-voltage of the graphitic constituents will necessitate a platinum black cathode. In Michailoff's problem with concentrated sulphuric acid the slow rate of corrosion is undoubtedly due to protective films of sulphate—see McCulloch, Am. Elec. Chem. Soc., 56, 1929, page 325—but it is difficult to see why these should prevent a reasonable correspondence. As Michailoff describes the cathode simply as "eine Platinelektrode," this may be responsible for part of the discrepancies which he records.

But apart from the lack of correspondence which may arise with this method of testing, there is a fundamental objection to its use. There is no evidence to show that in general a corroding metal can be divided up into well-defined anodic and cathodic areas, over each of which only the one process is taking place. True, a bi-metallic specimen may approximate to this state and one may be justified in drawing certain conclusions from such a method if the two electrodes consist of the two particular metals. Evans, Bannister and Britton, "Proc.," Roy. Soc., A. Vol. 131, 1931, page 356, however, find that with such combinations correspondence is not usually obtained, except under special conditions involving the bubbling of oxygen and the use of iron electrodes. But usually there is no such defined separation. Tödt himself asserts that the depolarisation at the cathode corresponds to the corrosion on a less noble metal of equal area corroding under oxygen control. That is to say, the whole of the corroding metal is assumed as functioning as a cathode. The work of Bengough, Lee and Wormwell,

"Proc.," Roy. Soc., A. Vol. 134, 1931, page 308, shows that in neutral solutions with totally immersed specimens of zinc and iron the whole metal surface behaves as a cathode and hydrogen bubbles have been described as streaming from the so-called anodic zones. Even with a bi-metallic specimen of iron and copper, Whitman and Russell, Ind. Eng. Chem., 16, 1924, page 276, found that the whole area was functioning as a cathode in running water, although the loss was only on the iron. It seems that in corrosion unstimulated by external electric effects it may be possible to distinguish the anodic areas from the cathodic ones, but it is not possible to separate the cathodes from the anodic areas. It is inevitable that the processes associated with alkali and corrosion products must be different when two separate metals are used instead of a single piece. The two processes are so intimate and cause such complicated conditions over the metal surface that it is doubtful whether it is possible to isolate one electrode process without interfering with the whole essential nature of the corrosion mechanism itself. The conclusions from such experiments will be usually subject to unknown limitations and their relation to the behaviour of the metal under the particular conditions can only be defined by comparison with an unstimulated corrosion experiment. Furthermore, an observation period of twelve hours or so is very risky for extrapolating to periods of a month's duration or more. This requires the shapes of the corrosion time curves, both stimulated and unstimulated, to be defined.

In view of the many pitfalls which beset the different electrical methods of judging corrosion rates, it seems that the safest and most reliable method for the study of the velocity and mechanism of corrosion is to obtain accurate measurements on metals corroding under a variety of defined external conditions in which the controlling factor has been ascertained.

White Metal Bearing Alloys.*

IN the continuation of his article, an account of which appeared in the August issue of THE METALLURGIST, Mr. Grant points out that although the lead-babbits are used extensively at present, they have not received as much investigation as the tin-base alloys, and cannot, therefore, be discussed quite as fully. As it is known that very careful and well-conducted researches are in progress on alloys of a similar character, but for another branch of industry, it may be anticipated that much well-authenticated information will be available during the next twelve months. All that has been said about the general characteristics of bearing metals in Part I. applies with equal force here.

The author reproduces Campbell's equilibrium diagram of the Pb-Sb-Sn system, which is similar to that of Heyn and Bauer. He reviews with special care the corner which applies to the alloys in general use as bearing metals—that bounded by the limits of 25 per cent. Sb and 25 per cent. Sn—and discusses the sequence of the separation of the various phases, notably the supposed first separation of pure lead, with its possible solution of Sn, to form a secondary phase. The low thermal points in the system are noted, the eutectic "E" (181 deg. Cent.), 64 per cent. Sn–0 Sb, "*d*" (184 deg. Cent.), 53·5 Sn–4 Sb, the reaction point "*b*" (242 deg. Cent. 10 per cent. Sn–10 per cent. Sb, and "E_2" (245 deg. Cent.) 0 per cent. Sn–13 per cent. Sb.

The Pb-base bearing alloys generally contain over 60 per cent. Pb, the remaining 40 per cent. being Sn and Sb in varying proportions, a small amount of copper is contained in certain alloys. Tin tends to harden, but does not cause brittleness, antimony hardens, but does cause brittleness. In these alloys 15 per cent. is the most usual amount of antimony present, whilst 25 per cent. may be regarded as absolutely the maximum. The author gives a useful tabulated summary of the structural constituents of the various fields shown in the equilibrium diagram. The various constituents can be recognised in favourable conditions under the microscope, but the author wisely points out that cast alloys will not have all the structure indicated because the comparatively rapid cooling prevents the reactions from going to completion. Annealing for 130 hours at 150 deg. Cent. favours the attainment of complete equilibrium and a better differentiation of the constituents. Further, the heating during working of a bearing in service may result in a partial annealing with consequent softening.

The practical bearing metals of this type lie within an area which is well defined, and the primary crystals may be Pb, γ, β and δ. The hardness of rapidly cooled ingots varies from a Brinell number of 5 for nearly pure lead to 35 for an alloy containing 25 per cent. each of Sn and Sb. All of these alloys which contain over 5 per cent. Sb show decrease in hardness if the quickly cooled alloy is annealed at 150 deg. Cent. Slow cooling also causes softening. Brittleness increases rapidly with hardness, but tin-rich alloys with less than 25 per cent. Sb are an exception. Segregation is a serious defect in some of these alloys. The cubes of Sn–Sb are specifically lighter than the lead-rich liquid and tend to rise. This can be controlled by rapid cooling, the casting conditions should, therefore, be controlled most carefully. Heyn and Bauer recommend rapid cooling. Rolfe points out that too rapid cooling is not good as a nearly homogeneous alloy is produced. Ellis made an extensive study of the effect of cooling, taking a typical alloy of 83·1 per cent. Pb, 12·1 per cent. Sb and 4·8 per cent. Sn. This investigation is worth close attention. He finds, as did Hudson and Darley on the Sn-base alloys, that pouring temperature had less effect than mould temperature. An increase in mould temperature reduced the resistance to slowly applied stress, as reported by Heyn and Bauer.

The addition of copper to lead-base alloys to overcome segregation is the most commonly used expedient. It is by no means easy, and its success depends upon the skill and experience of the operators. A well-known "brand" metal used with great advantage in railway work owes its reputation and success to its skilful preparation. Apart from this care one sees many disappointing results—6 per cent. of copper is generally the high limit. Ellis investigated the effect of 1 per cent. additions of copper, but did not determine the effect with certainty. The segregation was eliminated, not by the entanglement of the cubes by needles of Cu-Sn compound, but by a complete change of structure. The cubes are replaced by needles of "Regulus of Venus" Cu Sb, providing the pouring temperature is between 400 deg. and 500 deg. Cent. Only when the castings were poured into moulds heated to 200 deg. Cent. were the cubes of Sb Sn numerous. Ellis believes that this is due to

* Part II., by Leland E. Grant, *Metals and Alloys*, Vol. 3, July number.

a reaction between the Sb-Sn intermetallic compound with copper at temperatures above 400 deg. Cent., but as only a small proportion of copper is required to combine with the antimony it appears that some other cause is at work. This idea is supported by the observation that when both cubes and needles are found together, the cubes have a web-like, or non-homogeneous structure, as if the copper had entered into and affected them. The result to the practical engineer is an alloy possessing valuable anti-friction and wearing properties.

The addition of bismuth is sometimes advocated by claims that it reduces friction, owing to the high atomic volume of this metal. It is probable that bismuth was not added originally with this end in view. Mundey finds that it has been added to a melt with the object of lowering the melting point of fine particles entangled in the dross, thus facilitating cleaning. The risk of producing a small quantity of low-melting eutectic, thus creating the danger of wiping, has to be considered. Mr. Grant gives some illuminating notes on investigations by Freeman and Brant, and also by Rorst and Pascoe on the effect of arsenic on the lead-base babbitts. It is held to increase the hardness and yield point, it affects the microstructure, altering to some extent the form of the cuboids, with less than 0·5 per cent. present. The operator during manufacture notices a marked grain refinement or, as he terms it, a "tightening up" of the fracture, and also a peculiar sheen and smooth surface on the finished ingots. Traces of arsenic are generally present; the investigator finds little to complain of in the resulting physical properties, but it is generally agreed that it makes the metal less inclined to adhere to the backing or shell if present in appreciable quantities (above 0·25 per cent.). This last fact is sufficient to cause the engineer to regard arsenic with grave suspicion.

The engineer user of bearing metal alloys naturally desires a summary of the relative properties of tin-base and lead-base babbitts. Tin-base alloys are more expensive to buy than lead-base, but as a larger bearing surface is advocated in the use of the latter, and as the tin-base alloys are specifically lighter, there are some compensations in this respect. Tin-base alloys have a higher compressive strength and Brinell hardness than lead-base generally. Their elastic limit is higher and the loss in compressive strength of lead-base on prolonged heating, to 100 deg. Cent. under constant load, is marked, whilst tin-base alloys are practically unaffected. On the other hand, a typical lead-base alloy can be compressed to 46 per cent. without cracking; a tin-base alloy cracks at 33 per cent. compression. Lead-base alloys are said to wear less rapidly than tin-base, but the latter dissipate the heat more rapidly and are the more suitable for high speeds.

Nothing has been said in this excellent correlated abstract about running tests. Engineers and large users will look with interest for a complementary record of work in this field, if such be possible.

Tempering of Steels Containing Vanadium.

IT has long been known that certain steels containing vanadium, when hardened and tempered, do not show a progressive fall in hardness with rise in tempering temperature, but that their hardness falls to an almost steady value which is maintained over a range of tempering temperatures approximately from 500 deg. to 625 deg. Cent., afterwards diminishing rapidly as the temperature of tempering is raised. For example, the American Vanadium Company, in a brochure entitled "Vanadium Steels," issued in 1912, gave the tests shown in Fig. 1, A and B, for a nickel-vanadium as compared with a nickel steel. A similar

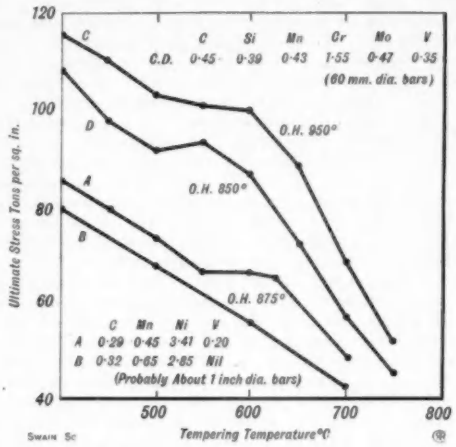

FIG. 1—*Effect of Tempering on Hardened Steels Containing Vanadium. A.B. Nickel Steels With and Without Vanadium (American Vanadium Co., 1912). C.D. Chromium-Molybdenum-Vanadium Steel (Houdremont, 1932).*

behaviour was indicated by tests on chromium-vanadium steel. Secondary hardening effects due to the formation of martensite were well known at the time in steels which contained austenite after quenching, but this explanation was not applicable to the behaviour of the nickel-vanadium or chromium-vanadium steel, as there was no reason to suppose that the quenched steel contained austenite, and, if it did, an austenite of that composition should have been completely decomposed into martensite at a temperature as low as 300 deg. Cent., whereas the hardening effect in the vanadium steels only became evident on tempering at a much higher temperature.

In a paper on "Vanadium in Structural Steels," published in 1924, R. Hohage and A. Grützner* showed that in a mild steel (carbon 0·14 per cent.) containing 0·30 per cent. of vanadium quenched from 950 deg. Cent. and tempered at temperatures increasing from 300 deg. to 700 deg., the yield point and ultimate tensile strength of the steel, after an initial decrease due to tempering, increased again with rise of tempering temperature above 500 deg. and passed through a maximum on tempering at 600 deg. The elongation, reduction of area, and impact value showed a corresponding change and passed through a minimum at 600 deg. A chromium steel containing 0·20 per cent. carbon and 1·0 per cent. chromium was compared with a similar chromium-vanadium steel (carbon 0·23, chromium 1·09 per cent.) containing 0·34 per cent. vanadium. While the tensile strength of the chromium steel fell steadily with increasing tempering temperature, that of the chromium-vanadium steel, after an initial fall, suffered no further reduction on tempering at all temperatures between 500 deg. and 600 deg. Cent. Both yield-

* *Stahl und Eisen*, 1924, 44, 1713.

point and tensile strength were slightly higher after tempering at 600 deg. than after tempering at 500 deg., although elongation did not suffer any diminution, as in the carbon-vanadium steel.

This behaviour of steels containing vanadium has quite definitely shows that the effect which has been described above is connected with the presence of vanadium, that it is consistent with the superimposition of a hardening process on the usual softening effect induced by tempering, and that it is probably

TABLE I.—*Effect of Duration of Tempering on the Mechanical Properties of Vanadium Steels, oil-hardened from 950 Deg. and Tempered at 600 Deg. Cent.*

Composition, per cent.		Time of tempering. Hr.	Yield point, tons per square inch.	Ultimate stress, tons per square inch.	Elongation, per cent. ($l = 5\,d$).	Reduction of area, per cent.	Impact figure.* mkg./cm.².
C.	V.						
0·04	0·31	1	27·3	30·3	29·0	79	30·0
		8	30·5	36·3	26·4	78	22·6
0·36	0·37	1	57·8	64·4	18·4	57	7·9
		8	54·6	63·4	18·2	55	8·5

practical importance in that, by a close control of composition, the mechanical properties which correspond to the flat part of the tempering curve are obtainable, as a matter of routine, with treatments which may vary within fairly wide limits. On the

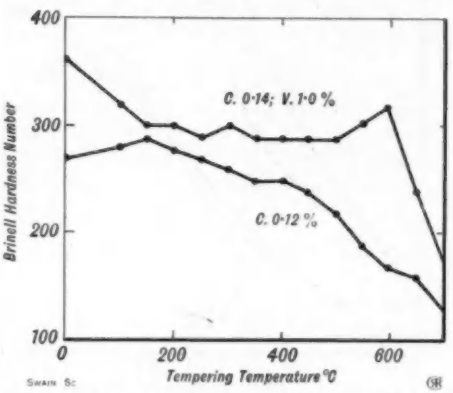

FIG. 2.—*Effect of Tempering on the Hardness of Steels Quenched in Water from 1000° C.*

other hand, if in any particular steel the specified tests can only be obtained by tempering at a temperature above 620 deg. they may be very difficult to achieve with regularity, since fall in hardness with rise in tempering temperature is very rapid.

due to temper-hardening produced by the deposition of vanadium carbide from solid solution in α iron.

The difference in behaviour of mild steel, with and without vanadium, when quenched in water from 1000 deg. Cent. and tempered, is shown in Fig. 2. The vanadium steel shows a maximum hardness after tempering at 600 deg., the carbon steel after tempering at 150 deg. Cent. When the carbon content is 0·04 per cent., so that little total variation in hardness is obtained by treatment, a maximum hardness is reached after tempering for one hour at 650 deg., four hours at 600 deg., and over 100 hours at 500 deg. Similarly, a 0·36 per cent. carbon steel containing 0·37 per cent. of vanadium, after being quenched, softens continuously on tempering at 650 deg., remains at fairly constant hardness between one hour and ten hours at 600 deg., and rises steadily in hardness on tempering at 500 deg., after the initial fall in the first hour (Fig. 3). Mechanical properties after tempering for one and for eight hours are given in Table I., while in Table II. the relative absence of mass effect in carbon-vanadium steel which has been subjected to prolonged tempering is illustrated. The method of determining the yield point, the reported figures for which appear to be very high, is not stated. The small mass effect is due to the fact that the occurrence of temper-hardening renders the properties of the steel less dependent on rate of cooling through the critical range, but the low impact figure, which is a disadvantage, is unfortunately a characteristic of temper-hardened material. The hardening effect in plain carbon steels containing vanadium occurs over approximately the same range of tempering tempera-

TABLE II.—*Influence of Section on the Mechanical Properties of Steel Containing 0·36 Per cent. Carbon and 0·37 Per cent. Vanadium Oil-hardened from 1000 Deg. and Tempered at 500 Deg. Cent. for 100 Hours.*

Diameter of specimen.	Position of test.	Yield point tons per square inch.	Ultimate stress, tons per square inch.	Elongation, per cent. ($l = 5\,d$).	Reduction of area, per cent.	Impact figure,* mkg./cm.².
20 mm.	—	66·0	71·1	12·7	46	4·0
40 mm.	Outside	58·4	67·2	14·7	50	2·3
	Inside	57·1	66·5	16·0	49	1·7
60 mm.	Outside	56·5	66·2	14·8	45	2·2
	Inside	54·0	65·2	13·4	40	1·5

* Mesnager test piece (10 × 10 × 55 mm.) with 1 mm. radius notch, 2 mm. deep.

The explanation of this behaviour in vanadium steels is clearly indicated in a recent paper by E. Houdremont, H. Bennek, and H. Schrader† on "Hardenability and Stability on Tempering of Steels with Slightly Soluble Special Carbides." This paper

† *Archiv für das Eisenhuttenwesen*, 1932–33, 6, 24.

ture as that at which a check in the fall of hardness is observed in alloy steels containing vanadium, an effect which was again confirmed in this investigation by a determination of the tempering curves of a chromium-molybdenum-vanadium steel (Fig. 1, C and D).

Although the paper by Houdremont, Bennek, and Schrader is here quoted only in relation to the effect of tempering on vanadium steels suitable for constructional purposes, it should be mentioned that its scope is wider and that it deals also with high-carbon vanadium and tungsten steels and discusses such

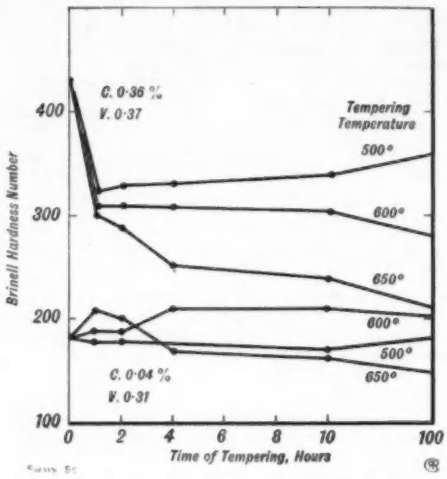

FIG. 3—*Effect of Duration of Tempering on the Hardness of Hardened and Tempered Carbon-Vanadium Steels.*

questions as the stability of high-speed tool steels containing vanadium and the strength of vanadium steels at high temperatures.

Tube Drawing.

IN spite of its great importance to industry, very little systematic research seems to have been done on tube drawing. The methods of drawing employed and the design of tools used vary greatly from one mill to another, and are, in many cases, the outcome of tradition rather than of scientific investigation. Special interest, therefore, attaches to any work which attempts to obtain accurate data on varying practice. W. Jung-Konig, W. Linicus and G. Sachs[1] have recently carried out a number of tests intended primarily to show the manner in which the draw-bench-load, or pull, is influenced by the method of drawing and the design of tools used, and while their work was confined to three alloys, 63 per cent. brass, annealed Lautal and semi-hard Lautal, they have arrived at a number of conclusions that are of general interest and show the importance of continuing the work on wider lines. In their investigations the three usual methods of drawing were considered—mandril, plug, and hollow-sinking—and the tests were carried out on a tensile testing machine, which applied the load with a speed of travel of 60/80 mm. per minute. To ensure adequate and constant lubrication the tubes and die-mouths were filled with rape-seed oil.

Six dies were used, all made in hardened tool steel (Bohler-Werkzeugstahl E Z H). Two were of trumpet-shaped contour—the so-called "radial bearing"—while the remaining four had straight tapers of semi-angles, 4 deg., 8 deg., 16 deg., and 25 deg. The two trumpet-shaped dies were lent by two different mills; the cone dies were specially made for the tests. Mandrils and plugs were also of the same hardened tool steel, but it is not stated whether the plugs had the slight taper usual in works practice. The surface finish of the die was found to have a large influence on the pull required, particularly in the case of the narrower angle dies. Fig. 1 shows for a number of dies the difference in pull required when the die was freshly polished and after it had been used for a

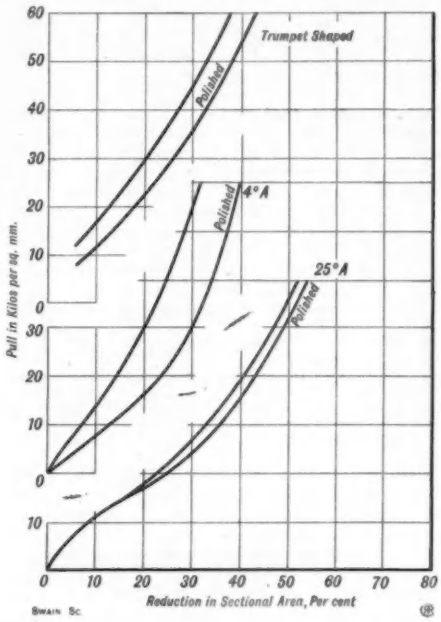

FIG. 1—*Influence of Polish of Die on Pull Required.*

number of tests. For the purpose of the remaining trials the dies were kept as highly polished as possible.

In the case of the mandril drawn and hollow-sunk brass tubes tests were included to determine the residual stresses in the drawn metal. The springing out of tongues and rings was measured to determine longitudinal and circumferential stresses in the manner originally suggested by Hatfield and Thirkell[2] and by Anderson and Fahlmann.[3] No attempt was made to calculate the stresses, as it was felt that any figure so obtained had little meaning owing to the uncertainty as to the manner in which the stresses were distributed through the tube wall. The actual springing-out offers a means of comparison and the mercurous nitrate test was applied to give an indication as to whether the stresses might be expected to lead to danger of season cracking.

The results of the tests are shown in the graphs reproduced in Figs. 1 to 4, and from them the authors draw the following conclusions:—

(1) For a particular die and with the same method

[1] W. Jung-Konig, W. Linicus and G. Sachs, *Metallwirtschaft*, July 15th, 1932.

[2] W. H. Hatfield and O. L. Thirkell, *Journal*, Inst. Met., 1919, 22, 67.

[3] R. J. Anderson and E. O. Fahlmann, *Journal*, Inst. Met., 1924, 32, 367.

of drawing, pull per unit area is directly proportional to reduction in sectional area.

(2) Pull is greater for plug drawing than for mandril drawing. With brass, the difference is small; with Lautal, and especially with narrow angle dies, the difference may amount to 70 per cent.

(3) Pull is less for hollow sinking than for mandril drawing, owing to the smaller surfaces in contact and the diminished pressure against the die face. With brass the difference is small; with Lautal the difference is more marked.

(4) Frictional losses with wide angle dies are little influenced by the method of drawing.

(5) Wide angle dies cause thinning of the tube wall in hollow sinking.

(6) Draw load decreases with increase in the

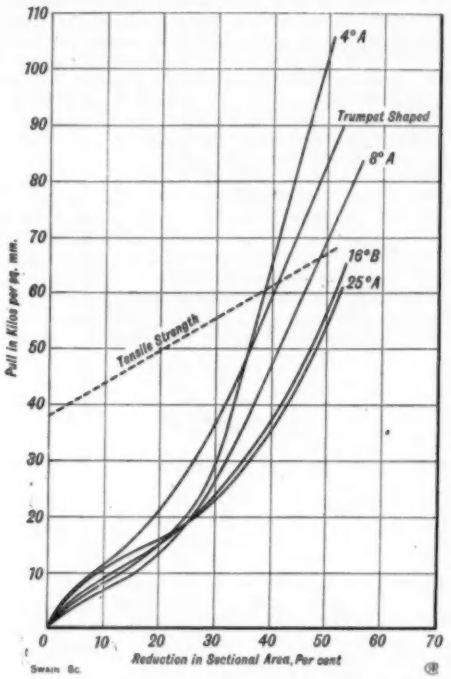

FIG. 2—*Influence of Die Shape on Mandril Drawing Brass Tube.*

angle of the die. With heavy draughts the relation is regular; with light draughts there is some crossing of the curves, probably because of uneven flow of the metal.

(7) With light draughts the increase in tensile strength with drawing is approximately the same as would result from the same reduction by simple stretching, as in a tensile testing machine.

(8) Trumpet-mouthed (radial bearing) dies appear to be exceptionally inefficient.

(9) Whereas the maximum pull possible is limited in the cases of hollow sinking and plug drawing to the ultimate strength of the material being drawn, in mandril drawing, owing to the help and support given to the tube by the frictional thrusting forward of the mandril, a pull as much as 150 per cent. in excess of the ultimate strength of the material may be given.

(10) In mandril drawing the maximum draught can be increased by using a rough mandril, as this helps to take more of the load from the tube.

No attempt is made to show on a graph the results of the tests for residual stresses, but they can be summarised as follows:—

(1) Residual stresses in drawn brass tubes increase with the angle of the die. This suggests that season cracking can be prevented by giving tubes a final draw through a narrow angle die.

(2) Residual stresses are greater in hollow-sunk than in mandril-drawn tubes.

(3) In mandril-drawn brass tubes danger of season cracking, as shown by the mercurous nitrate test, is at a maximum for reductions between 5 and 22 per cent. Susceptibility decreases with decreasing die angle and with a 4 deg. semi-angle die had vanished.

In considering these conclusions the German authors make comparisons with previous work of a similar nature on wire drawing. The importance of die polish had been shown by Linicus and Sachs,[4] who found that by using tungsten carbide dies instead of steel in drawing brass wire, falling off in efficiency

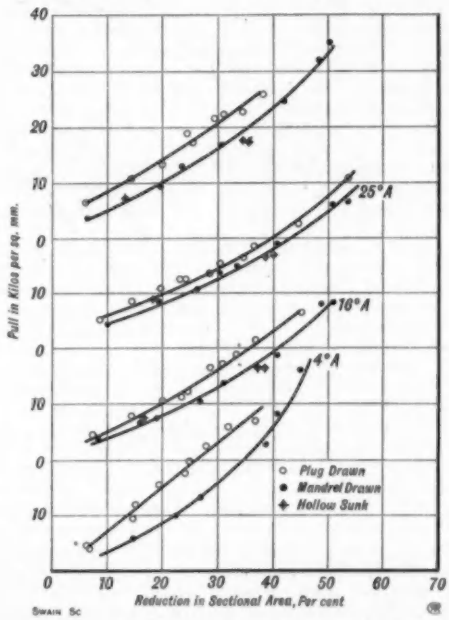

FIG. 3—*Pull Required with Annealed Lautal Using Various Dies and Drawing Methods.*

could be prevented. The authors, referring to previous work by Linicus and Sachs,[4] claim also that wire drawing confirms their conclusion that frictional losses, and, consequently, draw load, become less as the angle of the die increases. This is in complete disagreement with the work of Francis and Thompson,[5] who have shown that for wire there is an optimum angle of die, this optimum being independent of reduction in sectional area, of speed of drawing, of material of

[4] W. Linicus and G. Sachs, Mitt, Mat. Prüf, Anst, Sonderh. 16 (Spanlose Formung), (1931), S. 38/67.

[5] E. L. Francis and F. C. Thompson, *Journal*, Inst. Met. 1931, 46, 313.

die, and within the limits of their experiments, of type of lubricant used and metal drawn. This optimum for wire they found to be 6 deg. semi-angle, which would lead one to suspect that for tube drawing a similar angle would obtain for hollow sinking, and an angle twice as large for mandril or plug drawing, where the operative angle is that between die face and mandril or plug. It is important to notice, however, that when carrying out this work on wire, Francis and Thompson found that when using steel dies and a range of lubricants, the draw load, while almost constant over a wide range of speeds, became erratic and unstable below a certain minimum speed, being, in some cases, considerably higher at very low than at more normal, practical drawing speeds. The speed used by the present authors is that which, with Francis and Thompson, gave about the maximum

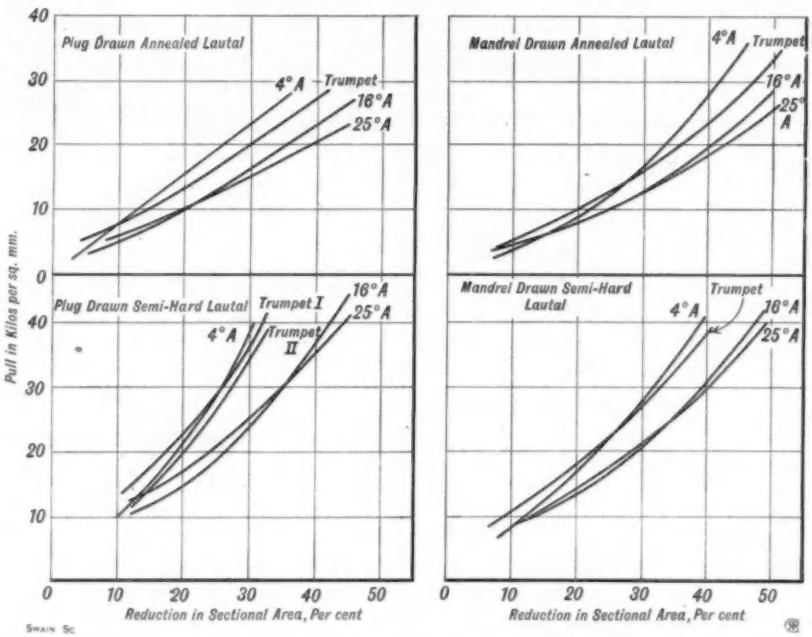

FIG. 4—*Comparison Between Various Types of Die Used in Drawing Lautal.*

either in wire or tube drawing, is a practice difficult to justify.

The conclusion that with brass tubes and with small reductions of area the tensile strength after drawing differs little from the tensile strength which would be reached after simple stretching, agrees with the observation made by Alkins[6] when working with copper rods.

In considering the pull needed in plug drawing the very important factor of plug design seems to have been overlooked. Slight tapering of the plug can reduce greatly the frictional losses and, consequently, the pull needed when compared with a plug of cylindrical form. This question of plug design might well form the subject of further research.

The figures given in connection with residual stresses and susceptibility to season cracking in divergence from normal with brass wire. Francis and Thompson ascribe this behaviour (which they did not find with tungsten carbide dies) to failure of adequate lubrication, and it seems possible that the very slow speed employed in the work at present under review may have influenced the results in the same way. For this reason it would be interesting to see the tests repeated with a drawing speed more nearly approaching normal mill practice. Further tests on hollow sinking are also desirable, as the conclusions appear to have been drawn from inadequate data.

In view of the widespread use in the trade of trumpet-shaped dies, it is interesting to find that this work shows that for tube drawing, as Francis and Thompson showed was the case for wire drawing, this type of die is much less efficient than a plain conical die. The agreement of two separate sets of investigators on this important point suggests that the continued use of the so-called radial bearing die, mandril-drawn tubes, would have greater value if the proportion of " sink " in the reduction of sectional area were given, since it is this component that is mostly responsible for the unevenly stressed condition. In practical working quite moderate draughts are found to be safe so long as due care is taken that " sink " is kept to the absolute minimum. The authors finally suggest that since residual stress and tendency to season crack both diminish as the angle of the die is reduced, it may be possible to abolish the risk of season cracking in brass tubes by giving a final draft through a narrow angle die. If this should prove to be the case, it would be possible in practical working to do away with the final low-temperature annealing, now considered imperative with all hollow sunk or lightly draughted tubes. Much more extended work is needed, however, before such a course could be adopted with a feeling of complete confidence.

[6] W. E. Alkins, *Journal*, Inst. Met., 1931, 46, 304.

Manganese Bronzes.

By EDMUND RICHARD THEWS.

THE commercial alloys generally known as "manganese bronzes" contain 55 to 58 per cent. copper, 37 to 40 per cent. zinc, 0·75 to 1·50 per cent. iron, 0·20 to 3·0 per cent. manganese, 0·2 to 1·5 per cent. tin, 0·2 to 1·0 per cent. lead, and 0·5 to 2·5 per cent. aluminium. The term "bronze" is therefore a misnomer, alloys of this type being most fittingly characterised by the term "high tensile brasses." This misnomer is due to the fact that the first manganese-copper alloys introduced by P. M. Parsons were real copper-tin-iron-manganese bronzes; when the tin was later replaced by larger percentages of zinc,[1] the name persisted.

Properly made manganese bronzes are strong, ductile, corrosion-resistant and non-magnetic metals widely used in electrical and automotive work, although the major portion of the manganese bronze produced finds its application in marine engineering—that is, for propellers, marine engine fittings, gun mountings, conning tower castings, torpedo tube casings, &c., or wherever good corrosion-resistance and ductility must be combined with steel-like strength and resistance to heavy stresses. Manganese bronzes are also recommended for steam turbine blading, high-pressure cylinders, valves, gear and sheave wheels, &c.

Apart from the minor constituents named above, some other elements are sometimes added to attain, or improve on, some special properties. Thus, nickel and cobalt additions tend to increase corrosion resistance and strength values considerably. Table I.

TABLE I.

	a.	*b.*	*c.*	*d.*
Copper	51·75	54·80	58·00	48·00
Tin	—	—	0·50	0·50
Zinc	40·50	38·36	37·00	46·45
Lead	—	—	—	0·10
Aluminium	0·25	—	1·00	0·20
Nickel	5·00	0·07	0·50	2·00
Manganese	1·50	2·79	1·80	1·75
Iron	1·00	1·72	1·20	1·00
Cobalt	—	2·16	—	0·08

gives the composition of four propeller alloys containing nickel and/or cobalt.

It is obvious, of course, that even within so limited a range of alloys as the propeller manganese bronzes, the composition may vary considerably. Whilst, as a general rule, propeller alloys should be as ductile as is compatible with the purpose involved in order to permit of straightening the propellers if bent through contact with rocks, &c., high-speed propellers—driven by turbines, &c.—which have wide blades with thin edges, must be made of a stiff metal in order to retain their shape. The tensile strength of these alloys may thus vary from 60,000 lb. to 95,000 lb. per square inch, with elongation of from 15 to 25 per cent. High strength alloys of this type are the "Turbadium" and "Tensilite" bronzes (see Table II.), the tensile strength of the former being 80,000 lb. to 94,000 lb. per square inch, with elongation about 15 per cent.

It should be pointed out in this connection that strength and ductility of these alloys are not determined by composition alone, but that their mechanical and chemical properties are greatly influenced by the melting and pouring processes as well as by the type of heat treatment adopted.

[1] About 1888 by Parsons.

EFFECT OF COMPOSITION.

Perfect homogeneity, a chief requirement of manganese bronzes, is attained only with alpha and beta structures. Of these, the latter structure prevails in the case of the alloys of this type. In order to avoid the presence of even traces of gamma constituent, which causes serious brittleness, the *zinc* equivalent of these alloys must not vary beyond 46 to 49 per cent. With an average zinc content of 40 per cent. the remainder of the required quota must therefore be filled by other alloying constituents. According to the observations of Guillet and Lambert,[2] the equivalent zinc values of various metals are as follows:—Aluminium, 1=6 of zinc; silicon, 1=10; tin, 1=2; lead, 1=1; iron, 1=0·9; manganese, 1=0·5. Nickel acts like copper in this respect, 1·2 units of this element being equivalent to 1 unit of copper.

Manganese acts as a strong deoxidising agent, although 4 units of this metal are equal to only 1 unit of phosphorus in this respect. However, while the latter element causes deterioration of the mechanical properties of brasses if added in excess, manganese forms a very desirable constituent, increasing strength, elastic limit and hardness of these alloys, and improving their hot working properties. In straight manganese brasses, containing more than about 2 per cent. of manganese these improvements are accompanied by a corresponding decrease of elongation and shock resistance, but the addition of the other minor constituents present in "manganese bronzes" causes a primary improvement of these properties as well as a further improvement in strength—without a corresponding reduction of elongation—on mechanical treatment.

Iron in amounts of from 1 to 2 per cent. tends to improve the elongation of manganese bronzes. The author has found that the addition of about 1 per cent. iron to a straight manganese brass (60/39/1) caused an increase in tensile strength and elongation of about 10 per cent. Iron also improves the corrosion resistance of "manganese bronzes," although the peculiar fact exists that iron-rich mixtures of this type tend to corrode much faster at first than the other corrosion-resisting bronzes. However, this action is confined to the surface only, the life of these alloys being considerably prolonged by their iron contents.

Corrosion resistance and strength of commercial manganese bronzes are further improved by the addition of 1 to 3 per cent. of *nickel* or *cobalt*, the latter element giving higher strength values but slightly lowered elongation.

Aluminium increases the corrosion resistance, tensile strength, elastic limit, and hardness, but also the brittleness of manganese bronzes, although the other constituents of these alloys counteract the latter tendency. Aluminium also neutralises some of the deleterious effects of lead and improves the sand casting properties of these alloys.

Lead is the chief impurity found in manganese bronzes, being introduced by the spelter employed. Small quantities of this element do not appear to deteriorate appreciably the mechanical properties of these bronzes; larger percentages, tending to segregate, lower the shock resistance and ductility. The larger the castings, or the wider the freezing interval, the lower are the permissible lead contents.

[2] Paper read at a meeting of the Manchester Metallurgical Society on January 14th, 1931.

American authorities have placed the maximum lead content of commercial manganese bronzes at 0·4 per cent., and while for general practical purposes this specification may be justified, attention is called to the fact that the absolute solubility of lead in beta brasses, such as the "manganese bronzes," is about 0·90 per cent. With correct production methods lead contents of up to about 0·6 per cent. appear to be perfectly safe. The valuable properties of the delta alloys (Table II.), all of which contain certain percentages of lead, prove this contention.

It is not necessary, therefore, to employ extra high-grade zinc, as some authorities suggest. Fairly good spelter containing about 1 per cent. lead and giving a lead content in the finished alloy of about 0·40 per cent., will be perfectly satisfactory for this purpose.

Vickers[3] claims that good manganese bronze can be produced with spelter containing as much as 1·5 per cent. lead, pointing out that a high lead content in the spelter can easily be offset by a higher aluminium content in the alloy.

Only where highest tensile strength combined with a fair degree of elongation is required (as for ship propellers, &c.) the lead contents should for safety's sake be maintained as low as possible, only high-purity zinc being permitted in this case.

Tin is a regular constituent of earlier manganese bronzes, such as Parsons' and Stone's bronzes, its chief advantage being the noticeable increase of rigidity and yield point of the alloys. In view of the fact that a number of failures have apparently been traced to the presence of tin, modern alloys—particularly the super-high-tensile brasses recently developed—are practically free from tin. However, in order not to increase the cost of the alloys unnecessarily, about 0·50 per cent. tin may well be allowed, whilst in some cases where maximum rigidity of castings is required, as much as 1·25 per cent. tin may prove to be of advantage. Higher percentages (about 1·50 per cent. and more) cause serious brittleness, rendering the alloy unfit for rolling, drawing, and other mechanical treatment. Besides improving certain mechanical properties, tin increases the fluidity and density of the alloys.

It is interesting in this connection to note that, according to Johnson[4] and Hanser[5] hard and heterogeneous constituents are formed in presence of both lead and tin, which tend to lower the ductility of these alloys, and that for normal ductility, tin and lead must not exceed 1·00 per cent. and 0·50 per cent. respectively. Where high strength and mechanical workability are demanded rather than maximum elongation, lead may be present up to 2 per cent. with tin not above 0·5 per cent., whilst for the production of highly tenacious, but good rolling and drawing alloys tin should be maintained at the lowest possible minimum, with lead not above 1 per cent. These results of Johnson and Hanser may explain some of the disagreeing results obtained with commercial manganese bronzes containing tin.

PRODUCTION OF MANGANESE BRONZES.

Manganese bronzes may be melted in crucibles and electric furnaces, but ordinary cupola furnaces have also been successfully employed. In the latter case the copper and the ferro-alloy used as "hardener" are run through the cupola and tapped into ladles, where zinc and aluminium are added as required. It is practically impossible, however, to obtain a homogeneous melt by this method unless the mixture is repeatedly poured back and forth from ladle to ladle. The cupola blast used in melting down the copper-steel alloy mixture is about the same as that used for iron. According to Vickers,[3] this process is applicable even to the casting of propellers.

The composition of the ferro-alloys used for this purpose differs with requirements. They contain in general about 54 to 57 per cent. iron, 25 to 30 per cent. tin, and 10 to 15 per cent. ferro-manganese. All the constituent metals charged should be of fair quality, although extreme purity is not required. Virgin copper and zinc should be tolerably pure, the latter

TABLE II.

	Copper, per cent.	Zinc, per cent.	Tin, per cent.	Lead, per cent.	Aluminium, per cent.	Iron, per cent.	Manganese, per cent.	Nickel, per cent.
Admos	61·25	35·1	0·39	0·35	—	0·88	1·26	0·10
"	57·24	40·4	0·63	0·22	0·40	0·63	tr.	0·10
Delta Metal	55·00	40·0	—	1·00	—	1·00	1·00	—
" (castings)	55·90	41·6	—	1·80	—	0·87	1·00	—
" (forgings)	55·80	40·1	—	0·80	—	1·30	1·80	—
" (rolling)	55·80	41·4	—	1·10	—	0·86	1·40	—
" (hot pressing)	54·20	42·3	—	0·70	—	1·00	1·10	—
Manganin	53·40	39·0	2·66	—	—	—	1·70	2·50
Parsons' Bronzes:								
" (original)	58·00	40·0	—	—	1·00	—	1·00	—
" (castings)	56·1	41·3	0·75	—	0·47	1·30	tr.	—
" (sheets)	60·3	37·6	0·75	—	—	1·40	0·10	—
"	61·70	34·2	1·30	—	—	—	2·80	—
"	56·60	40·5	1·20	—	—	1·50	0·10	—
"	58·00	38·5	1·00	—	—	1·00	0·50	—
"	60·15	34·8	0·94	—	0·23	1·20	2·34	—
Rübel bronze	56·45	40·0	—	—	0·31	1·26	—	2·00
" "	53·35	40·0	—	—	0·90	2·10	5·40	—
" "	52·15	40·0	—	—	0·25	2·30	3·20	2·10
" "	51·15	40·0	—	—	0·25	2·50	4·00	2·10
Stone bronze	58·00	39·0	0·25	—	0·75	1·50	0·50	—
Turbadium	48·00	46·45	0·50	0·10	2·00	1·00	1·75	2·00
Turbiston	55·00	41·0	—	—	1·00	0·84	0·16	2·00
Super-manganese bronze	69·00	20·0	—	—	6·50	2·50	2·00	—
Tensilite	64·00	29·1	—	—	3·13	1·40	2·45	—
"	67·00	24·0	—	—	4·40	—	3·80	—

The compositions given represent characteristic analyses, those of practically all the special alloys named varying with requirements.

[3] Charles Vickers, "Metals and their Alloys," 1923, page 434.

[4] *Internationale Zeitschrift für Metallographie*, 1912 (II.), page 273.

[5] *Zeitschrift für Metallkunde*, 1924 (XVI.), page 93.

containing not more than about 1 per cent. lead. If brass scrap is employed, only such material should be chosen as is known to be fairly pure and of constant composition. Rolled and drawn brass scrap, stampings, shapes, &c., fulfil this requirement, whilst all the other alloying constituents used must be examined as to the kind of impurities carried. Zinc dross from galvanising plants, for instance, may be employed to form part of the zinc contents of the manganese bronze, and this material is frequently used to supply the iron specified for the alloy. If enough iron can be obtained in this manner, a "ferro-alloy hardener" may be dispensed with, the manganese being introduced as a copper-manganese alloy of suitable composition. Re-melted zinc may also be employed for this purpose if the total impurities do not exceed about 2 per cent., with lead, tin, and iron as chief impurities. The author has found a re-melted zinc, 97·8 per cent. pure, with 1·2 per cent. lead, 0·6 per cent. tin, 0·2 per cent. aluminium, and 0·15 per cent. iron to give perfectly satisfactory results, although only half of the total zinc contents of the alloy consisted of re-melted material, the remainder being added in the form of virgin zinc.

In order to prevent burning of the melt a fluid slag should be provided, any of the common brass slag mixtures being satisfactory. Common salt-charcoal mixtures (1 : 1) are frequently employed for this purpose; they are usually added to the cold charge. Other slag mixtures consist of the carbonates of soda and potash, borax, boric acid, &c. Soda and potash mixtures are preferable to the respective single salts, fluidity and fluxing properties being considerably improved. The same is true of borax-boric acid mixtures. If too fluid, these fluxes may give trouble when cleaning the metallic surface previous to pouring, but it is easy to stiffen them by the addition of a handful or two of fine sand or fire-clay meal.

Some disagreement still exists as to the use of charcoal or other reducing agents in the fluxes or slags, but recent experimental results seem to indicate that the favourable influence of reducing slags in preventing oxidation of the metal is more than neutralised by their tendency to cause gassing of the brass alloys. A neutral slag, protecting the melt against the oxidising and gassing influences of the atmosphere, will yield a denser alloy than reducing slags of the type indicated.

It is important to keep melting and pouring temperatures as low as possible, the various pouring temperatures given by authorities ranging from 1800 deg. to 2000 deg. Fah. (980 deg. to 1100 deg. Cent.). The latter figure, suggested by Gillett, is undoubtedly too high for most purposes, although the pouring temperatures depend upon a number of factors such as composition of alloy, size and shape of casting, &c. It seems quite certain, however, that a temperature range of from 1850 deg. to 1925 deg. Fah. (1010 deg. to 1050 deg. Cent.) suits practically all conditions.

Some authorities suggest the use of a small quantity of phosphor copper as deoxidising agent, others, in denying this necessity, point out that the alloy contains sufficient quantities of deoxidising metals and that further additions of deoxidising agents seem to be excessive. The latter assertion is correct in part only. Where virgin copper is used in the melt, phosphor copper additions are absolutely necessary to reduce the cuprous oxide always present in this material. The copper is melted down first, the other alloying constituents being added only after the copper has been deoxidised with a small excess of phosphor copper. A small phosphor copper addition may also be advisable immediately before pouring, when the phosphorus vapours generated will form a thin, but effective, protective gas envelope preventing direct contact with the atmosphere. It is true that the zinc vapours generated act in a similar manner, but part of the solid zinc oxide formed in the reaction remains on the surface of the metallic stream, being washed into the mould and contaminating the castings. In the presence of phosphor copper, oxidation of the zinc vapour begins only after the latter emerges from the layer of phosphorus vapour, the castings produced being much less liable to contamination with zinc oxide.

No matter how carefully the production process and how thorough the mixing of the melt before casting, it is practically impossible to obtain the best properties unless the alloy is re-melted and re-cast. Best results are obtained if the primary melt is cast into ingots, which are then re-melted and finally cast into the proper moulds.

Spring Steels.

The experimental work carried out on spring steels in this country during the past few years on behalf of the Springs Research Committee of the Department of Scientific and Industrial Research has greatly increased existing knowledge of the general properties and behaviour in service of spring steels, and other countries are now also giving detailed consideration to this important matter. The United States Bureau of Standards, for example, is at present preparing a general summary of all available data on springs, presumably with a view to further experimental work, whilst it is clear from a recent article in *Stahl und Eisen*, by E. Houdremont and H. Bennek,* that German engineers are endeavouring to apply scientific testing methods for obtaining reliable data for spring designers. It will be remembered that the most important conclusion drawn from the work of the British Springs Research Committee was that although British spring steels have high intrinsic fatigue-resisting properties, yet these properties are not realised in springs as normally used owing to the development of surface weaknesses which nullify, to a great extent, the advantages which should be gained by the use of properly treated high-grade material.

Further definite experimental confirmation of this conclusion is now given by Houdremont and Bennek in the article mentioned, and summaries of some of the more important results which they quote on this subject are reproduced in Tables I. and II. The values of the endurance fatigue limits S given in Table I., and also the ratios of these values to the ultimate tensile stress $\left(\frac{S}{\sigma_B} \cdot 100\right)$ are almost identical with the results of the more extensive tests on British spring steels carried out in this country. The agreement is so good that, as far as ordinary rotating bending fatigue tests on prepared polished specimens are concerned, it can now be said with a fair degree of safety that the results of such tests on any normal high-grade spring steel can be estimated from the tensile strength or the Brinell hardness. When results of bending fatigue tests on unmachined material are considered, however, the importance of the surface is at once realised.

* *Stahl und Eisen*, July 7th, 1932, pages 653–662.

Thus, Table II. shows results (originally due to E. Lehr) on various spring steels with the surfaces in the condition which exists in practice, and provide a striking confirmation of the results obtained in this country. Possibly, it will be some consolation to British spring steel manufacturers to know that the defective surfaces are common to all spring steels of normal manufacture. Messrs. Houdremont and Bennek do not attempt to deal in any detail with the underlying causes of the low fatigue resistance of unmachined spring steels. They mention the recent work of Hankins and Becker in this country in which it was shown that surface decarburisation of the material was an important factor in this matter; but, in general, it rather appears that the German authors consider surface irregularities of shape—that is to say, "surface notch effects"—to be the most important factor. Their treatment of the subject suggests that the object they have in view is the accumulation of fatigue test data on various spring steels with the idea of utilising the data for design purposes. They conclude (possibly somewhat prematurely) that the addition of various alloying elements does not greatly increase the fatigue resistance of unmachined springs, and suggest that, in general, laminated springs can safely be designed on a limiting fatigue stress in the material of $\pm 9\frac{1}{2}$ tons per square inch, and helical springs on a fatigue stress (torsional stress) of $\pm 6\frac{1}{2}$ tons per square inch. They also suggest that the effect of mean stress can be allowed for in design by use of a diagram similar to the well-known modified Goodman diagram, but using the static yield stress of the material instead of the ultimate tensile stress as the upper limit in the diagram. There seems little doubt that springs designed on this basis would be fairly safe against failure by fatigue, but it also seems probable that such springs would be appreciably heavier than those now in general use. It is not essential for a laminated spring, for example, to be able to withstand many millions of application of the maximum stress cycle to which it may be subjected, and this fact appears to be utilised by designers.

Messrs. Houdremont and Bennek also deal at some length with such matters as manufacture and rolling of spring steel, practical heat treatment of laminated, helical, and buffer springs, comparison of railway spring specifications in various countries, resistance of springs to impact, and acceptance tests for springs. In regard to heat treatment they have found that manganese spring steels (1·75 per cent. Mn) have a much greater resistance to surface decarburisation than spring steels containing about 1·5 per cent. of silicon; they also find that these manganese steels, although somewhat sensitive to overheating, are usually more uniform in hardness

TABLE I.—*Mechanical Properties of Spring Steels.*

Composition, per cent.							Tensile strength, σ_B, tons/sq. in.	Yield stress, σ_s, tons/sq. in.	Extension, per cent. ($l = 5\,d$).	Fatigue limit, S, tons/sq. in.	$\frac{S}{\sigma_B} \times 100$.
C.	Si.	Mn.	Cr.	Ni.	Mo.	V.					
0·50	1·8	0·70	—	—	—	—	93	87	11	39*	48
							77	69	12	38	51
0·44	—	1·80	—	—	—	—	77	69	9	38	50
0·45	—	0·85	1·1	—	—	—	83	76	11	41	49
0·34	—	—	1·3	—	—	0·3	83	76	12	44	53
0·33	—	—	1·3	—	0·5	0·35	88	82	13	46	52
0·58	—	—	1·3	4·2	0·4	—	78	68	14	41	52
0·40	—	—	1·5	4·2	0·4	0·3	91	78	12	47	52

* Given as 61·5 kilos./mm² in original paper; probably a misprint for 70 kilos./mm.² (44 tons per square inch).

TABLE II.—*Bending Fatigue Strengths of Various Steels.*

	C., per cent.	Si, per cent.	Mn, per cent.		Tensile strength, tons/sq. in.	Mean stress, tons/sq. in.	Fatigue limit, tons/sq. in.	Condition.	Surface.
Siemens-Martin steel	0·08	0·2	0·5	—	26	0	±10	As rolled	With rolling scale
Steel, 37·11	0·12	0·05	0·42	—	24	0	± 9·5	,,	,,
Steel, 48·11	0·34	0·21	0·71	—	31	0	±13	,,	,,
Silicon steel	0·1	1·02	0·76	—	34	0	±15	,,	,,
Copper manganese steel	0·4	0·64	1·0	0·58 Cu	36	0	±17	,,	,,
Chromium copper steel	0·16	0·48	0·54	0·4 Cr, 0·7 Cu	32	0	±16	,,	,,
Chromium nickel steel	0·1	—	—	0·8 Cr, 3·5 Ni	70	+25	±11	Hardened	,,
							±27	,,	Ground
Chromium vanadium steel	0·54	0·25	0·8	1·1 Cr, 0·23 V	84	+25	±15	Oil hardened	With rolling scale
							±14	Air ,,	,,
							±12	Oil ,,	,,
Chromium vanadium steel	0·5	—	—	1·3 Cr, 0·2 V	91	+25	±13	,, ,,	,,
					83	+25	±14	,, ,,	,,
Spring steel	0·5	1·6	0·56	—	70	+25	±11	Hardened	,,
						+32	±9	,,	,,
						+25	±10	,,	,,
Chromium vanadium spring steel	—	—	—	—	73	+25	±16	Oil hardened	,,
					76	+25	±30	,,	Ground
Manganese spring steel	—	—	—	—	93	+25	±31	,,	,,
					84	+25	±12	,,	With rolling scale
Manganese steel	0·53	0·23	1·6	—	92	+25	±15	,,	,,
					84	+25	±13	,,	,,
					76	+25	±14	,,	,,
Manganese steel	0·5	0·4	1·8	—	91	+25	±11	,,	,,
					83	+25	±10	,,	,,

throughout the section after quenching and tempering than most other spring steels. On the question of the resistance of springs to impact, Messrs. Houdremont and Bennek express the view that impact resistance of the steel is unimportant in normal practice, and that notched bar tests on the material are unreliable owing to the effect of laminations and slag streaks. Thus, a steel containing appreciable laminated slag and inclusions, and, accordingly, not a good steel, may give a higher notch bar test result than a cleaner and better steel in which the notch bar test is uninfluenced by inclusions. The German writers include in their article a table which summarises current acceptance tests for laminated springs (apparently railway springs) in Germany, France and England. They suggest that acceptance test on springs should serve to (1) verify the condition and treatment of the material, (2) check the correct assembly of parts, (3) give consideration to the behaviour in practice. In regard to (2) they make no comment, but regarding (1) they are of the opinion that the tensile test, Brinell test, and the static bending test (used in British railway acceptance tests) are all suitable.

They also mention that the more detailed tests in German specifications, such as determination of tensile yield stress, and elongation, are often omitted in actual practice. In regard to (3) these authors point out that Germany has gone further in this matter than other countries in requiring that the completed spring should be subjected to sixty successive loadings as part of the acceptance test. The authors appear to have had considerable experience of this test, and in their opinion it is valueless for laminated springs.

Messrs. Houdremont and Bennek also discuss, to a limited extent, the question of corrosion fatigue of springs. They draw attention to the work of McAdam and Mailänder on corrosion fatigue, but conclude that in practice corrosion fatigue of unmachined springs is not very important, since, although the surface effect and the corrosion fatigue effect is each by itself very important, the two actions are not cumulative; accordingly, corrosion fatigue has no very marked effect on a spring steel in which the fatigue resistance of the material is already greatly reduced by the defective surface. No definite experimental evidence is given on this matter, and on the authors' assumption that both corrosion fatigue and surface effects are entirely dependent on stress concentration arising at actual or virtual surface notches, their argument is reasonable. The soundness of their original assumption may be doubted, but their conclusion, that the effect of the surface on unmachined spring steel and corrosion fatigue effects are not cumulative, is strongly supported by the way in which many vehicle springs continue to function when marked corrosion also occurs.

A New British Standard for Gold Wares.

By ERNEST A. SMITH, A.R.S.M.

IT is well known that the precious metals industry differs from all others in the fact that the raw materials available for manufacturing purposes consist chiefly of a series of legally standardised alloys, the quality of which is maintained by compulsory hall-marking at specified assay offices. Consequently, any alteration in these legal standards is a question of some importance to all manufacturers of jewellery and gold wares. It may, therefore, be of interest to draw attention to some recent alterations in the standards that will be available to the industry in the future. It is now more than three-quarters of a century since any alteration was made in the legal gold standards and the alterations now made are due to the changed conditions in the industry.

Five gold standards have been legalised in the past. The two higher ones of 22-carat (91·7 per cent. gold), and 18-carat (75 per cent. gold) have been in use for several centuries, but the three lower standards of 15-carat (62·5 per cent. gold), 12-carat (50 per cent. gold), and 9-carat (37·5 per cent. gold) were not legalised until 1854. Of these lower standards the 9-carat quality gradually increased in popularity, and at the present time about one-half of the gold wares submitted for hall-marking are of this grade. Gold of 15-carat quality has found application in the production of jewellery of slightly lower cost than 18-carat gold, of which all the high-class jewellery is made. The intermediate standard of 12-carat gold has, however, found little favour in the jewellery trade, and wares of this standard are rarely submitted for hall-marking. It has therefore long been regarded by manufacturing jewellers as more or less obsolete, and it is not surprising that its abolition has been sought. In these circumstances it has been felt for some time by certain sections of the jewellery trade that some change was desirable in the standard alloys available for manufacturing purposes. The alterations now agreed upon have been made with a view to meeting the changed condition of present-day industry, more especially in regard to the export trade, the former British standards not being the same as those in other jewellery-producing countries.

At the International Jewellery Congress held in London in May, 1931, it was recommended that gold of 14-carat quality, which has found such extensive use in America and on the Continent, should be made a legal standard in this country. Following this recommendation steps were taken by the Worshipful Company of Goldsmiths to ascertain the opinion of the trade generally on the proposal, and although some objections were not unnaturally raised, the final decision was in favour of some alteration. In consequence, on August 8th last, Orders-in-Council were issued legalising 14-carat gold (58·5) as a standard for gold wares, and abolishing the two standards of 15-carat and 12-carat quality.

The new standard is legalised as from August 15th, whilst the 15-carat and 12-carat standards remain in operation until October 1st. Actually, 14-carat gold contains only 58·33 per cent. of fine or pure gold, but for convenience the standard is legally fixed at 58·5 per cent. gold, and this slightly higher quality will be required for hall-marking purposes. The 14-carat standard is by no means a new quality to British goldsmiths, as it was in use during last century for the production of the so-called coloured jewellery—that is, superficially coloured—that became very popular during the Victorian era. Gold of 14-carat quality appears to have been first used in the fourteenth century by the goldsmiths of Montpellier, in France, who adopted it as the standard for the production of gold wares at that time, but later raised the quality. The mechanical properties of the new standard alloys are more akin to those of 15-carat alloys than to those of 12-carat, the 14-carat alloys containing only 4 per cent. less fine gold than 15-carat. The carat golds for industrial

purposes usually consist either of the binary alloys gold-silver, and gold-copper, or of the ternary alloys gold-silver-copper. By keeping the gold content constant at 58·5 per cent. and altering the proportions of silver and copper, it is possible to produce a considerable range of alloys of 14-carat quality differing materially not only in colour, but in mechanical properties and quite suitable for the manufacture of all classes of gold articles. To modify the colour small quantities of zinc are sometimes added, whilst for the production of white golds of 14-carat quality the characteristic yellow colour is bleached by the addition of nickel, or of palladium.

It remains to be seen whether the 14-carat quality gold will become as popular in this country as it has become in recent years in America and Germany, and elsewhere on the Continent. The existing laws relating to the hall-marking of gold alloys of legal standard are applicable to the new 14-carat standard.

Books and Publications.

Foundrywork and Metallurgy. A Practical and Authoritative Guide for Moulders, Patternmakers, and Apprentices. Edited by R. T. ROLFE. London: Sir Isaac Pitman and Sons, Ltd. Six volumes. 6s. each.

THIS treatise, which appeared in a large number of weekly parts, is now available in six bound volumes with a total of 1463 pages. The manner of publication —a distinct innovation for metallurgical subjects— in itself aroused considerable interest, but a fair estimate of the value of the work could hardly be formed until the numerous sections had been brought together in book form.

There seems to have been some uncertainty in the editor's mind as to the type of reader for whom the books are intended—the sub-title describes the publication as "a practical and authoritative guide for moulders, patternmakers and apprentices," but in the preface to the first volume "it is felt that not only the student, but also the advanced technician will find matter of interest and profit," while the final sentence of the last volume claims that "the work should serve in some measure as an encyclopædia of foundry work and metallurgy for some time to come." If the sub-title would appear to be unduly modest, the description "encyclopædia" errs in the opposite direction, and the true scope of the treatise probably lies somewhere between these extremes.

Each of the twenty-one sections is written by a specialist. Mr Rolfe himself deals with Non-ferrous Metallurgy, Ferrous Metallurgy, Pyrometry, Metal Melting, Cast Iron Specifications, Testing, and Alloy Cast Irons, while other well-known names are those of the late Mr. Dews (Brass and Bronze Casting), Mr. Mundey (Die Casting), Mr. Hurst (Centrifugal Casting), and Mr. Searle (Refractories).

Reference will probably be made to these volumes by many who, being specialists in one field of applied metallurgy, wish to obtain information on up-to-date practice in other branches. The work can be warmly recommended to this type of reader, and from this point of view the sections on Moulding and Core-making, Centrifugal Casting, Die-casting, and Steel Foundry Practice should be widely appreciated. Of the chapters dealing with subjects of more general interest, those devoted to Refractories and Pyrometry merit the attention of all works metallurgists and foundry managers.

The only section which arouses serious criticism is that contributed by the editor on Non-ferrous Metallurgy, which, according to the introduction, is intended to equip the student with the fundamental knowledge of metallurgical principles requisite for the production of better castings. Some impression of the task which the author has set himself in this section may be gathered from the fact that in sixty-three pages he attempts to deal with metallography almost from A to Z, touching on the formation, growth and orientation of metallic crystals, the nature of boundaries and the amorphous theory, atomic structure and the various types of crystal space lattice, solid solutions, and passing, *vid* the determination of heating and cooling curves, to the constitutional diagram, discusses segregation, degassing, overheating, shrinkage, and design of castings. The attempt to achieve this extraordinary condensation has resulted in the omission of points which it is essential to explain if the mind of the uninformed reader is not to be hopelessly confused. Thus, no reference is made to the Phase Rule, although the constitutional diagrams, of which it is the fundamental basis, are dealt with on a highly theoretical system. Microstructures are shown, but the use of the microscope is not discussed. Cooling curves are given as inverse-rate curves without any explanation of their relation to direct time-temperature curves. There is little doubt that the author of this section would have been better advised, in the limited space at his disposal, to be content with a much more elementary treatment of the fundamentals of the subject, and to refer those whose interest was thus aroused to one or other of the more comprehensive treatises on metallography.

Considering the number of different authors and the close relationship between the subjects on which they have written, there is remarkably little overlapping. Where repetition does occur it is fairly natural, as, for instance, in the case of Seger cones, which are discussed in the chapter on Refractories and again under Pyrometry. The Ajax-Wyatt furnace is described in Section XI. in connection with Metal Melting, and again in Section XII. on Brass and Bronze Casting. Incidentally, in view of the obviously increasing importance of electric melting, a fuller treatment of the subject would have been welcome; for example, the value of this section would be greatly enhanced by a consideration of the electrical characteristics and the means of generation of the high-frequency oscillatory circuit in the Ajax-Northrup furnace.

Evidence of the care taken in production and proof-reading is provided by the rarity of misprints. By a slip of the pen an aluminium bronze containing no zinc is described on page 337 as a complex brass; Snyder is mispelt on page 885, and on page 1133 an elongation of 130 per cent. on 2in. is attributed to the aluminium alloy "R.R. 53" (D.T.D. 131). The number 130 is, no doubt, intended to refer to the Brinell hardness—the omission of the first two digits would give a value approximating more closely to that usually obtained for the elongation of this alloy.

Bound in red covers the six volumes, which are of a convenient size, make an attractive set; the type is clear, the paper good, and the illustrations are excellently reproduced. The editor and the publishers are to be congratulated on carrying through so successfully a production which will prove of value and interest to all concerned with the making of castings and the technical control of foundrywork.